STUDYING THE PROCESS OF TRANSPORT EQUIPMENT COOLING SYSTEM ULTRASONIC CLEANING

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Resume

The article deals with the existing methods of cleaning vehicle radiators from sedimentary scale. A method of cleaning radiator tubes by ultrasonic radiation is proposed. An experimental bench has been developed for studying ultrasonic cleaning processes. Based on the results of the experiment, dependences have been obtained that determine the efficiency of the process depending on the mass of scale removed and the liquid outflow rate from the tubes. There are proposed the purification degree coefficients. The hypothesis about the possibility of cleaning radiators with ultrasonic vibrations has been confirmed.

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1 Introduction

A radiator is an element of the cooling systems of the internal combustion engine of road transport that consists of thin-walled tubes through which the coolant flows, and tanks-reservoirs connecting the tubes into a single unit (Figure 1) [1]. The radiator provides the desired temperature range of the engine coolant by giving off excess heat to the flow of air passing through the radiator.

Radiators for various purposes are mounted on road transport depending on the design of the vehicle:

- a radiator of the engine cooling system;
- the vehicle interior heater radiator;
- an oil radiator;
- the air conditioning and evaporator radiators;
- an intercooler radiator.

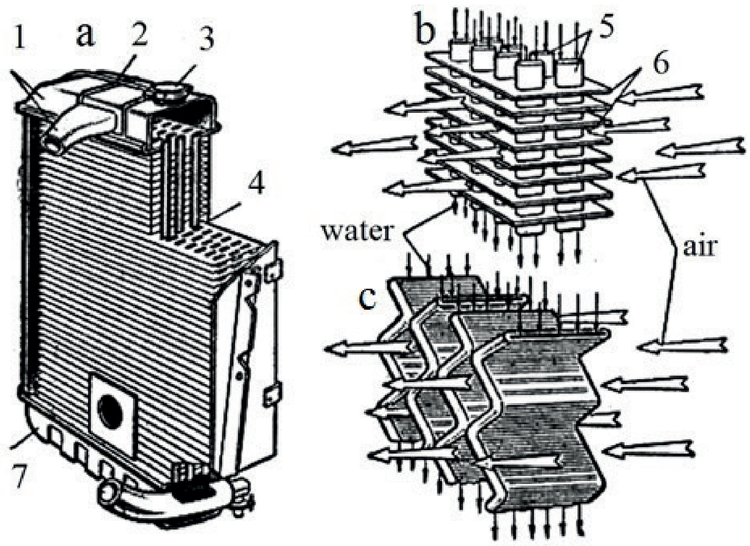
These radiators can be significantly different in appearance but fundamentally of the same design [1]. The main designs of automobile radiators are shown in Figure 2.

Reliable operation of the internal combustion engine in transport equipment is impossible without a good cooling system [2]. Proper maintenance of the cooling system increases the engine life. Maintenance of the cooling system is mainly reduced to the timely replacement of the coolant and flushing the cooling system. Deterioration of the technical condition of the engine leads to deterioration in the environmental situation, a large emission of exhaust gases into the atmosphere. This in turn contributes to the development of pulmonary, cardiac and other diseases [3].

The operation of the internal combustion engine cooling system consists in cooling the engine by removing excess heat and transferring it to the radiator that releases it into the atmosphere [4]. A coolant, such as antifreeze, constantly circulates in the cooling system keeping the engine temperature within a certain range.

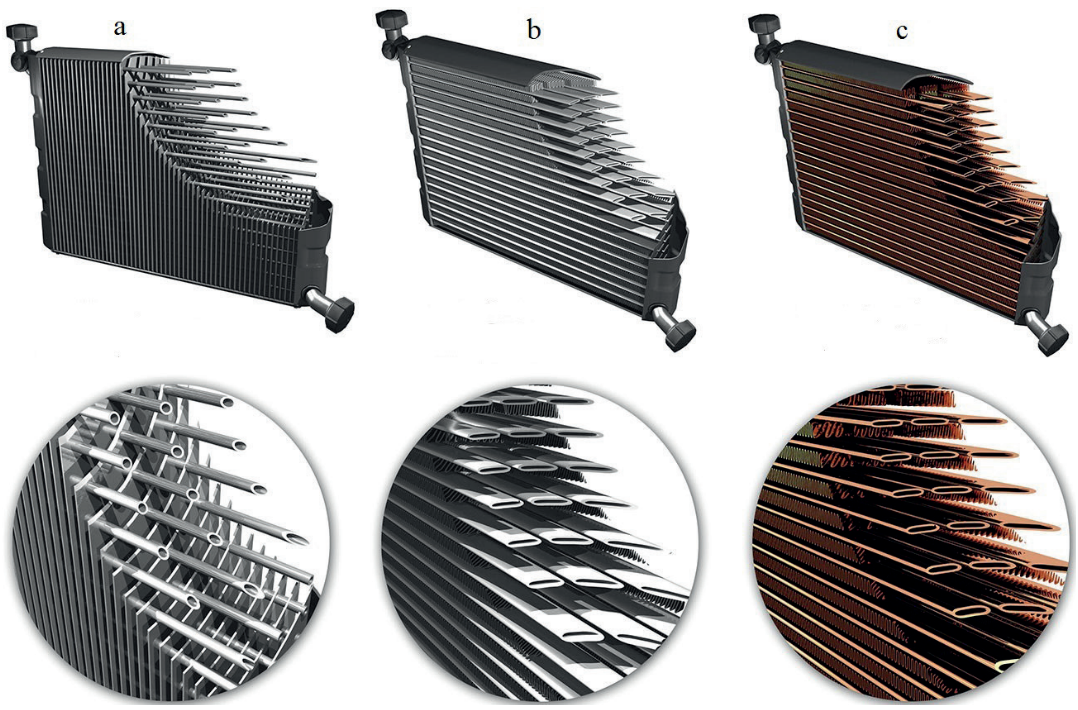
Antifreezes do not form scale but they are dangerous from a different point of view: they decompose over time, and their decomposition products affect adversely the cooling system. Rust, oxides and layers of various organic substances form on the internal surfaces of the metal components of the cooling system.

In the engine cooling system, metals of various properties are used. So, the radiator is made of brass or galvanized steel, the engine block head is made of aluminum alloy, and the cylinder block is made of cast iron or aluminum alloy. When cleaning, the reaction must occur between scale and a chemical reagent without affecting the



a - vehicle radiator device, b - tubular core, c - lamellar core, 1 - *upper tank with a pipe,* 2 - *steam pipe,* 3 - *filler neck with a plug,* 4 - *core,* 5 - *tubes,* 6 - *transverse plates,* 7 - *lower tank with a pipe*

Figure 1 *Vehicle radiator arrangement*



a - aluminum tubular-plate prefabricated radiator, b - aluminum tubular-band brazed radiator, c - copper-brass tubular-band brazed radiator

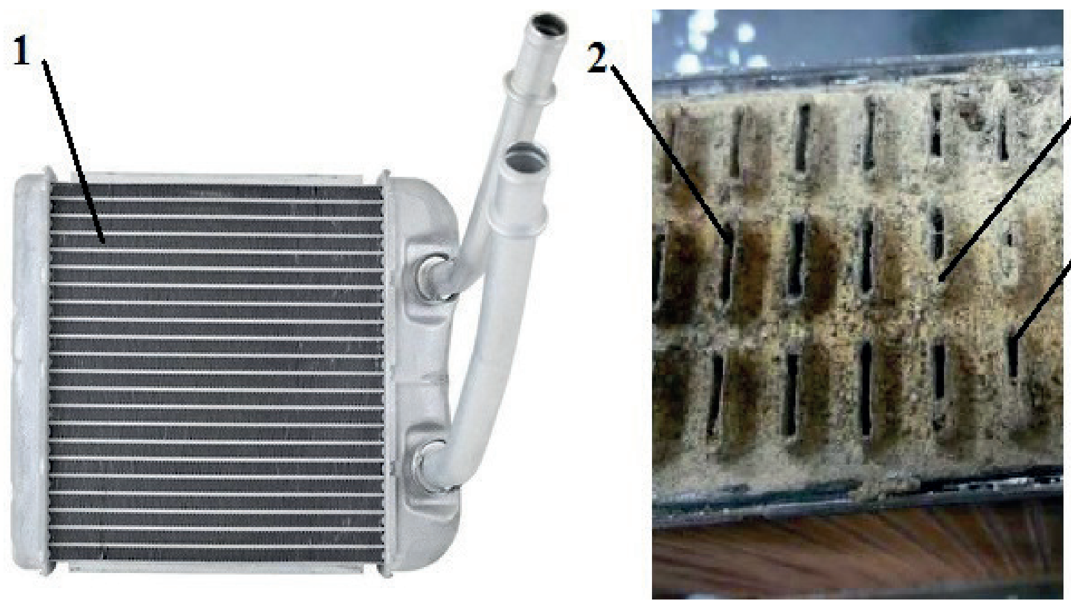
Figure 2 *Automobile radiators designs*

metal; this cannot be done because each type of pollution requires its own chemical action [5-8].

A variety of contaminants of different kinds penetrate into the cooling system: oils and other contaminants, detergents, dust, etc. Sealants that are often used to quickly repair damage to radiators and pipes sealants, which are often used for quick repairing damages to radiators and pipes, pollute seriously the system.

Scale, rust, oil-organic contaminants are deposited on the internal surfaces of the cooling system components. They have worse thermal conductivity compared to that of metals, they narrow the clearance of thin tubes (Figure 3). This leads to decreasing the efficiency of the cooling system and as a result, to engine overheating [9].

A labor-intensive process of maintaining the cooling system of motor vehicles is the cleaning of radiators from



1 - *interior heater radiator,* 2 - *tube,* 3 - *scale,* 4 - *scale-metal boundary*

Figure 3 *Scale deposits on the radiator tubes*

scale deposits formed on the walls of the radiator tubes. To date, the radiators of the internal combustion engine cooling system are cleaned by the chemical and mechanical methods. These methods have a number of significant drawbacks due to high complexity of the process, the detrimental effect on the components and the impossibility of using the method due to the design and type of the radiator [10].

The chemical method of cleaning radiators involves washing the radiator with distilled water and adding etching acids to it. At this, washing the radiator can be performed directly on the vehicle; to obtain the best result it is possible to dismantle the radiator from the vehicle [11-13].

After flushing the radiator, the flushing liquid is drained and clean water is poured, the procedure is repeated until the clean liquid flows from the stove radiator; then the radiator cleaning is considered complete. There is always a risk of damaging the vehicle radiator using chemicals to clean it that results in smudges and microcracks.

With the mechanical cleaning method, the remaining liquid is first drained from the cooling system and then the radiator is removed. To gain access to the tubes, at least one of the radiator tanks is unsoldered. The work for mechanical cleaning of tubes consists in the fact that a steel bar of the appropriate section and length is inserted into each tube, then a reciprocating movement is performed along the entire length of the tube while removing scale and internal deposits. If it is impossible to clean the tubes on one side, the second radiator tank is soldered and cleaned on the other side. The mechanical cleaning method is characterized by high labor intensity and the associated high costs of time and money for the cleaning process [14]. The radiator tubes are often damaged, and it comes into disrepair.

The authors propose to use ultrasonic vibrations to clean the radiator tubes. Ultrasonic cleaning is a method of cleaning the surface of solids in flushing liquid s or water, due to the impact of ultrasonic vibrations on them.

The cleaning process is characterized by the joint manifestation of various nonlinear effects that occur in the liquid when exposed to ultrasonic vibrations. These effects include cavitation, acoustic currents, sound pressure and sound capillary effect [15-17]. In particular, in the process of cleaning the radiator tubes, the effect of cavitation is observed that is accompanied by the formation of cavitation bubbles pulsating and collapsing near pollution, thereby destroying the layer of scale and other deposits [18-19].

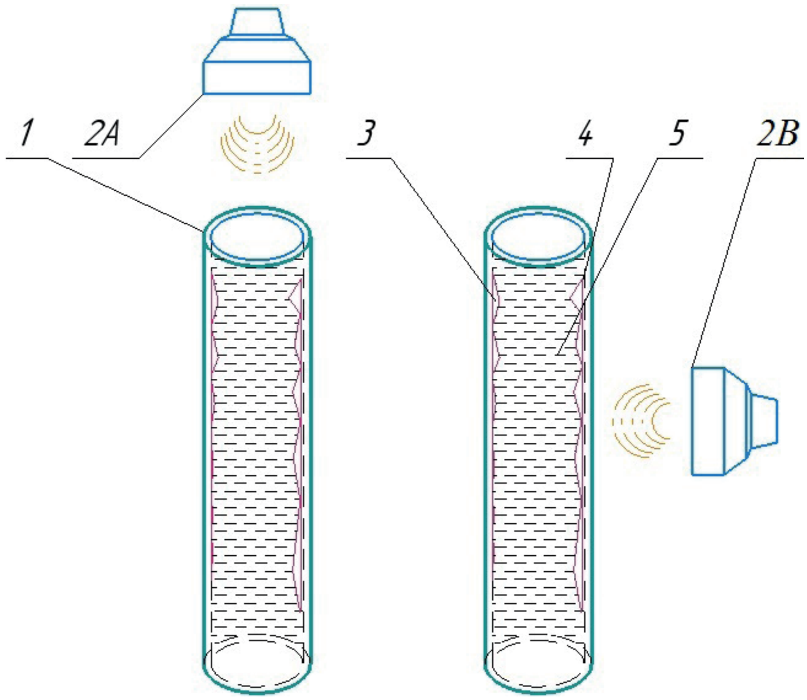
The method of ultrasonic cleaning does not require significant use of manual labor and other mechanical influences from the side and greatly simplifies the cleaning process. This removes flammable and toxic solvents from the cleaning process.

In this regard, the proposed method of cleaning the vehicle radiator from scale is relevant.

The hypothesis of the study is assumption of the possibility of cleaning the vehicle radiator from scale by ultrasonic action.

The purpose of the work is studying the process of ultrasonic cleaning, namely: establishing the dependences linking the exposure time of the ultrasonic generator to the mass of scale washed out from the heater radiator of a passenger vehicle, the temperature of the flushing fluid and the exposure time. For the initial study, the authors have selected a passenger car interior heater radiator.

To achieve the goal of the study, the following tasks have been solved: the analysis of literature sources has been performed on the possibility of cleaning the radiators of the cooling system of motor vehicles using ultrasonic waves; an experimental bench for ultrasonic cleaning the radiator has



1 - tube, 2A - longitudinal ultrasonic transducer, 2B - transverse ultrasonic transducer, 3 - scale, 4 - scale-metal boundary, 5 - water

Figure 4 *Diagram of the ultrasonic wave impact on the radiator tube*

been developed and the analysis of the results obtained has been carried out. The dependences have been obtained that determine the intensity of cleaning.

2 Materials and methods

Ultrasound is mechanical vibration of particles above 20 kHz. Ultrasound travels in the form of waves. To move ultrasound, unlike electromagnetic waves, an elastic medium is needed: a solid body, a gas, a liquid [20].

The main characteristics of ultrasonic waves are the length λ, the oscillation period T, the frequency of oscillations f, the speed of sound C in the propagation medium. There are longitudinal and transverse ultrasonic waves. Longitudinal waves coincide with the direction, displacement and velocity of the medium particles, and transverse waves propagate in the direction perpendicular to the plane, the direction of displacement and velocity of the body [21].

An important indicator is the power of ultrasound, that is, the energy transmitted by the wave through the surface under consideration per unit of time.

Ultrasonic dispersion is fine grinding of solids or liquids under the action of ultrasonic vibrations. Liquid dispersion in gases is called atomization, and liquid dispersion in liquids is called emulsification. Ultrasonic dispersion makes it possible to obtain highly dispersed mixtures with the particle size smaller than 1 μm, while mechanical dispersion allows obtaining particles with the particle size of up to 1-10 μm [21].

Grinding substances occurs under the action of shock waves and violation of the materials continuity. This helps to accelerate the cleaning of surfaces immersed in a liquid medium from contamination [22].

The difference between the proposed method and others consists in the fact that here the cleaning takes place without pouring a chemical liquid into the radiator and mechanical impacts but under the action of ultrasound on the tank wall scale [23].

In addition, the turbulent mode of fluid movement caused by ultrasonic vibrations is of great importance in the ultrasonic dispersion method [24].

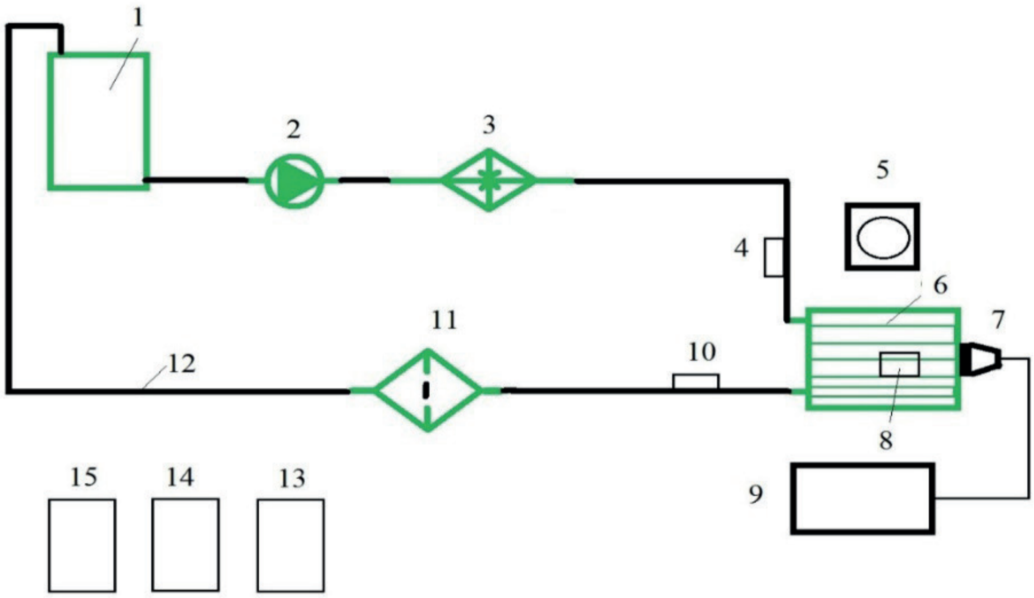
For the occurrence of the phenomenon of cavitation, the radiator tubes are filled with a liquid. The liquid has minimum viscosity, a sufficiently high temperature and is saturated with air. Plain water has a variable value of dynamic viscosity: at 0^oC - 1.977 Pa·s, at 40^oC - 0.655 Pa·s, at 80^oC - 0.357 Pa·s [25]. In this regard, water is needed for cleaning.

Since cavitation is the process of the air bubbles explosion in the liquid medium, the more saturated the water with air, the more efficient the process.

The ultrasound impact can be along the tube and across the tubes of the radiator (Figure 4). When exposed along the tubes, a longitudinal wave arises, and when the effect is transverse, a transverse wave arises.

With a transverse wave, it is necessary to cross the interface of the media several times: twice the walls of each tube, which leads to rapid attenuation of the wave. Preliminary experiments have been carried out that proved that the action of a longitudinal wave is more effective [26].

Figure 5 *experimental bench for ultrasound cleaning the car radiator*



1- reservoir for liquid; 2 - circulation pump; 3 - heating element; 4 - liquid temperature sensor on the inlet pipe of the radiator; 5 - axial fan; 6 - interior heater radiator; 7 - ultrasonic emitter; 8 - temperature sensor of the air flow passing through the radiator; 9 - ultrasonic generator; 10 - liquid temperature sensor on the outlet pipe of the radiator; 11 - filter; 12 - rubber pipes; 13 - device for controlling the temperature flow of the air passing through the radiator; 14 - device for monitoring the temperature of the liquid entering the radiator; 15 - device for monitoring the temperature of the liquid leaving the radiator

Figure 6 *Scheme of the experimental setup for car radiators ultrasound cleaning*

To test the effectiveness of ultrasonic cleaning, the authors have used experimental research methods.

The purpose of the experiment has been to confirm the proposed hypothesis.

The experiment has been carried out on a specially designed experimental bench for ultrasonic cleaning of car radiators (Figures 5-7).

The bench is a unit for cleaning radiators that consists of the following elements: a liquid reservoir, rubber pipes, a heating element, a circulation pump, a filter, an ultrasonic

1 - interior heater radiator; 2 - ultrasonic emitter; 3 - axial fan; 4 - circulation pump with a heating element; 5 - filter; 6 - reservoir for liquid; 7 - devices for temperature control; 8 - rubber pipes

Figure 7 *Placing the emitter on the interior heater radiator*

100 watt 40 kHz generator, an ultrasonic 50 watt 40 kHz emitter, temperature measuring instruments, an axial fan, a passenger car interior heating radiator (Figure 7).

The scheme of the experimental setup for ultrasonic cleaning of car radiators is shown in Figure 6.

Water with the lowest viscosity have been used as a flushing liquid for the heater radiator of a passenger car. Cavitation occurs most rapidly in water. Water of different temperatures has been used to determine the optimal temperature range.

The procedure of the experiment consist of two stages. At the first stage, the experiment has the following tasks:

1. Determining the parameters of pure water.
2. Determining the ultrasonic wave impact along the radiator tubes on the experimental becnh.
3. Determining water parameters after exposure to ultrasound.
4. Processing the obtained results.

The second stage of the experiment consisted of the following tasks:

1. Determining the parameters of pure water.
2. The ultrasonic wave impact along the tubes of the radiator with air saturation into water on an experimental bench.
3. Determining water parameters after ultrasonic exposure with saturation of additional air into the liquid.
4. Processing the obtained results.

In this regard, the following actions have been carried out at both stages of the experiment:

- the antifreeze has been drained from the radiator and antifreeze residues have been washed out with water;
- clean water has been poured into the radiator;
- the water has been drained from the radiator, the flow rate, mass and volume of the water have been measured to determine its density (Figures 8-9);
- the water has been poured, the ultrasonic exposure has been performed, the rate of water outflow, its density and the mass of scale released after exposure to ultrasound have been measured;
- the temperature of the inlet and outlet fluid passing through the radiator before and after exposure to ultrasound has been determined;
- the temperature of the air flow passing through the radiator developed by the axial fan has been determined.

To determine the efficiency of cleaning the radiator using ultrasonic exposure, the rate of water outflow from the tubes has been measured before and after exposure to the ultrasonic wave. By weighing, the mass and density of water and pulp (water + scale) have been determined.

The mass of scale has been determined in the following way: the mass of pure water has been taken from the mass

Figure 8 *Determining the liquid volume using a volumetric flask and the mass of liquid on the balance*

Figure 9 *Determining the liquid outflow rate through the radiator*

of the pulp and the mass of the washed scale has been obtained. The pulp is a liquid with scale obtained after exposure to an ultrasonic wave on the radiator. The scale is a solid deposit formed on the surfaces of heat exchange elements, on which the liquid is heated and cooled. Scale formation occurs not only due to decomposition of the coolant but also due to the ingress of engine oil, gasoline, grease, etc.

The same experiment has been carried out for water of various temperatures, and after saturation of the liquid with air. The water has been saturated with air by forcing it through a hose with a compressor.

The performance of a car radiator was determined by monitoring the temperature of the passing liquid at the inlet and outlet pipes of the radiator. With the help of a fan, a stream of air has been forced through the radiator that produced heat exchange between the air and the radiator. The air flow temperature has been controlled.

3 Results

The first stage of the experiment provides the effect of ultrasound on water that is poured into the radiator within 600, 1200, 1800 seconds.

The mass of the liquid, the pulp outflow time, its flow rate and temperature have been measured depending on

***Table 1** Parameters measured under the action of ultrasound*

Measured parameter	Unit of measurement	Exposure time, s.			
		0	600	1200	1800
Liquid mass (M)	Gram (g)	44.57	44.60	44.63	44.69
Liquid volume (V)	Milliliter (ml)	45	45	45	45
Liquid density (P)	Gram/cubic centimeter (g/cm^3)	0.9904	0.9911	0.9917	0.9931
Liquid outflow time (t)	Second (s)	1 liter within 9.93 seconds	1 liter within 9.73 seconds	1 liter within 9.22 seconds	1 liter within 9.20 seconds
Liquid outflow rate (U)	Milliliter/second (ml/s)	100.7	102.7	108.45	108.69
Liquid temperature (°C)	Celsius degree	51	51	50	51

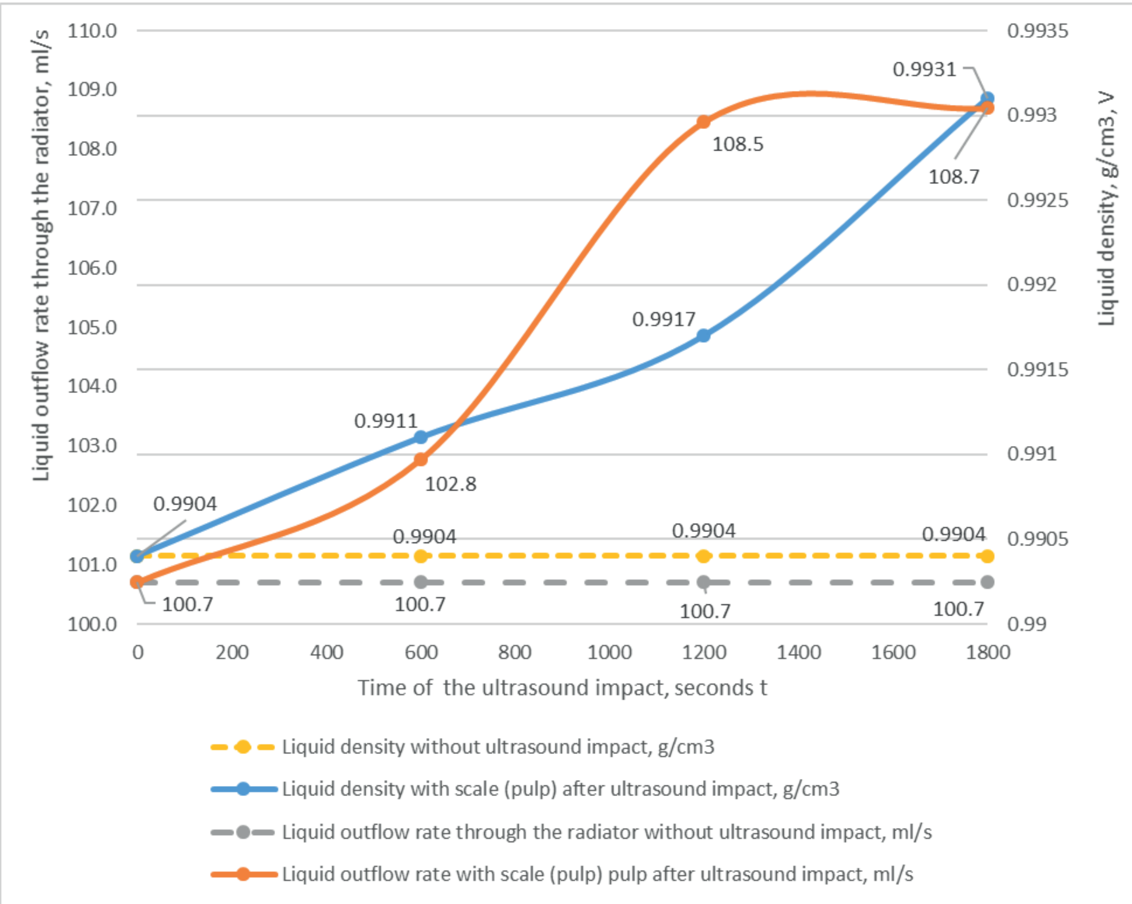


***Figure 10** Changing the liquid density outflow rate through the car radiator depending on the time of exposure to ultrasound*

***Table 2** Changing the mass of the pulp depending on the time of exposure to ultrasound*

Impact on the radiator	Liquid mass	Liquid mass increasing after the impact
Before exposure to ultrasonic wave, 0 seconds	44.57 grams	0 grams
After the first exposure to ultrasonic wave, 600 seconds	44.60 grams	0.03 grams
After the second exposure to the ultrasonic wave, 1200 seconds	44.63 grams	0.06 grams
After the third exposure to the ultrasonic wave, 1600 seconds	44.69 grams	0.12 grams

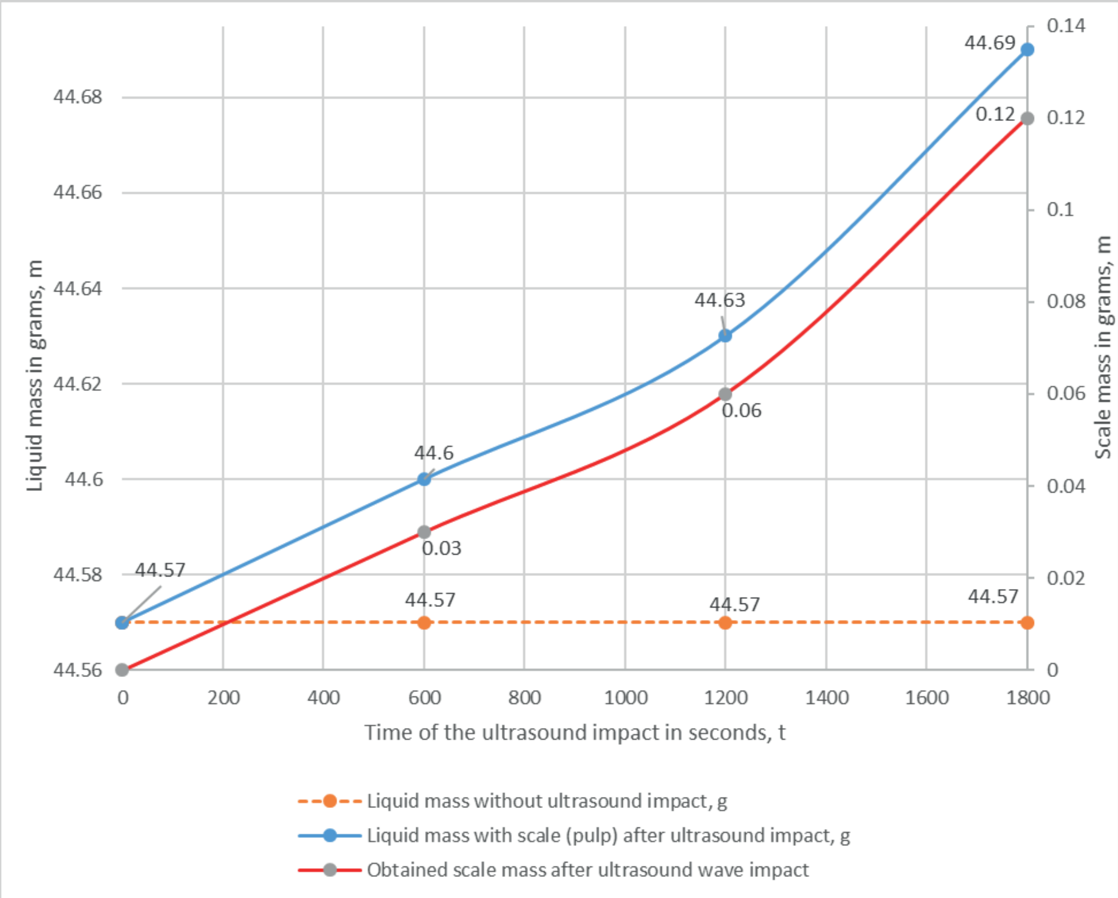


***Figure 11** The mass of pulp obtained depending on the ultrasound impact time*

the time of exposure to ultrasound. These parameters are shown in Table 1.

The processing of the experimental results made it possible to obtain the dependence of the fluid outflow rate through the car radiator and its density, which allows determining the intensity of tube cleaning (Figure 10).

It follows from the dependence in Figure 10 that, with increasing the time of exposure to ultrasound, the liquid outflow rate with scale (pulp) in comparison with pure water increases curvilinearly with the extremum in the area of the time of ultrasound impact of 1400 s.

Reducing the flow rate in the area of 1600...1800 s is determined by the fact that the radiator has been cleaned. The density of the pulp also increases with increasing the time of exposure to ultrasound and, consequently, with a greater transfer of energy.

Table 2 shows changing the mass of the pulp depending on the time of exposure to ultrasound

Figure 11 shows that there takes place increasing the pulp mass. This growth is curvilinear. According to the measurements, a graph of changing the mass of the pulp has been obtained. Subtracting the mass of pure water from the mass of the pulp, there has been obtained the mass of the washed scale.

The dependences obtained in Figure 11 confirm the assumption that it is possible to clean the radiator tubes with ultrasound. The scale content in the liquid increases in a curvilinear manner with increasing the time of exposure to ultrasound on the heater radiator of a passenger car.

During the experiment, the dependence of the outflow rate of the flushing liquid on the temperature has been established (Table 3), From the resulting graph (Figure 12) it follows that the outflow rate of the pulp almost linearly increases with increasing the temperature of the poured water. This is caused by decreasing its dynamic viscosity.

The optimum temperature for the ultrasonic dispersion

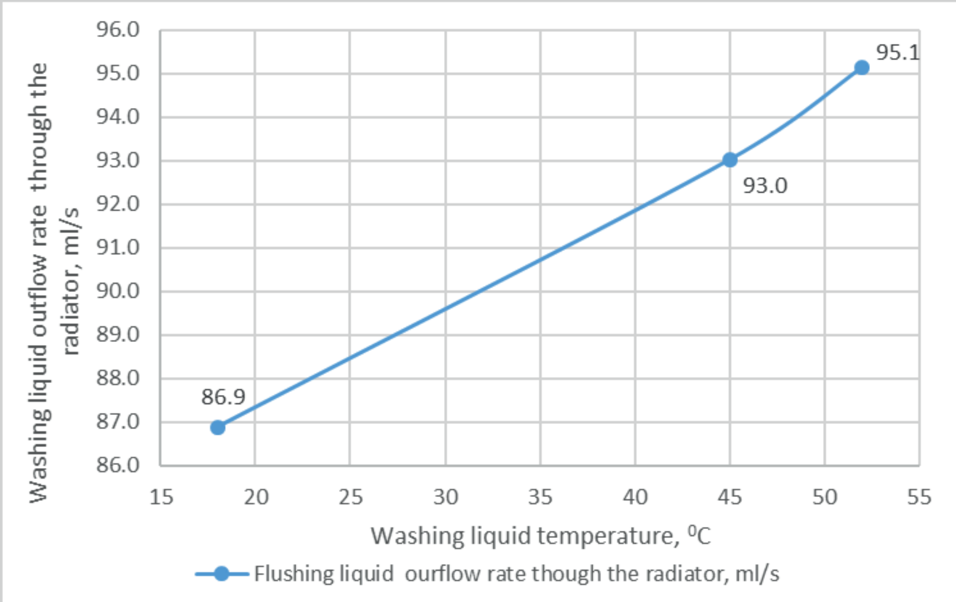


***Figure 12** Changing the liquid outflow rate through the radiator depending on the liquid temperature*

***Table 3** Coefficients that characterize the efficiency of the radiator cleaning*

Measured parameter	Exposure time, s.			
Ultrasonic exposure time	0	600	1200	1800
Fluid flow rate increase factor after exposure to ultrasound (K_U)	1	1.019860973	1.076961271	1.079344588
The coefficient of increase in the mass of the washed scale after exposure to ultrasound (Km)	1	1.000673	1.001346	1.002692
The coefficient of increase in the density of the liquid after exposure to ultrasound (K_p)	1	1.000707	1.001313	1.002726

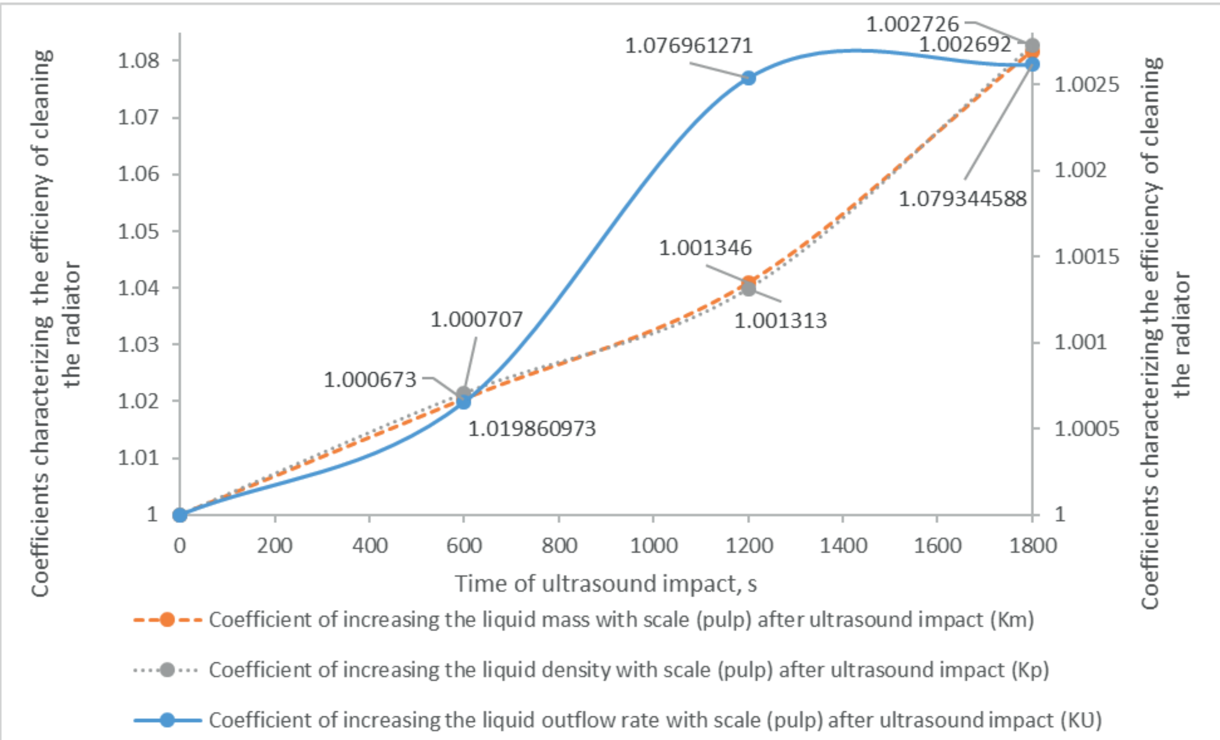


***Figure 13** Coefficients characterizing the efficiency of radiator cleaning*

***Table 4** Parameters measured under ultrasound impact with air*

Measured parameter	Unit of measurement	Impact time, s.		
		0	Ultrasound impact, 600 s.	Ultrasound +air impact, 600 c.
Liquid mass (M)	Grams (g)	44.52	44.57	44.65
Liquid volume (V)	Milliliters (ml)	45	45	45
Liquid Density (P)	Grams per cubic centimeter (g/cm³)	0.9893	0.9904	0.9922
Liquid outflow time (t)	Seconds (s)	1 liter within 9.21 seconds	1 liter within 9.18 seconds	1 liter within 9.17 seconds
Liquid flow rate (U)	Milliliter per second (ml/s)	108.6	108.9	109.1
Liquid temperature (°C)	Celsius degrees (°C)	50	51	51

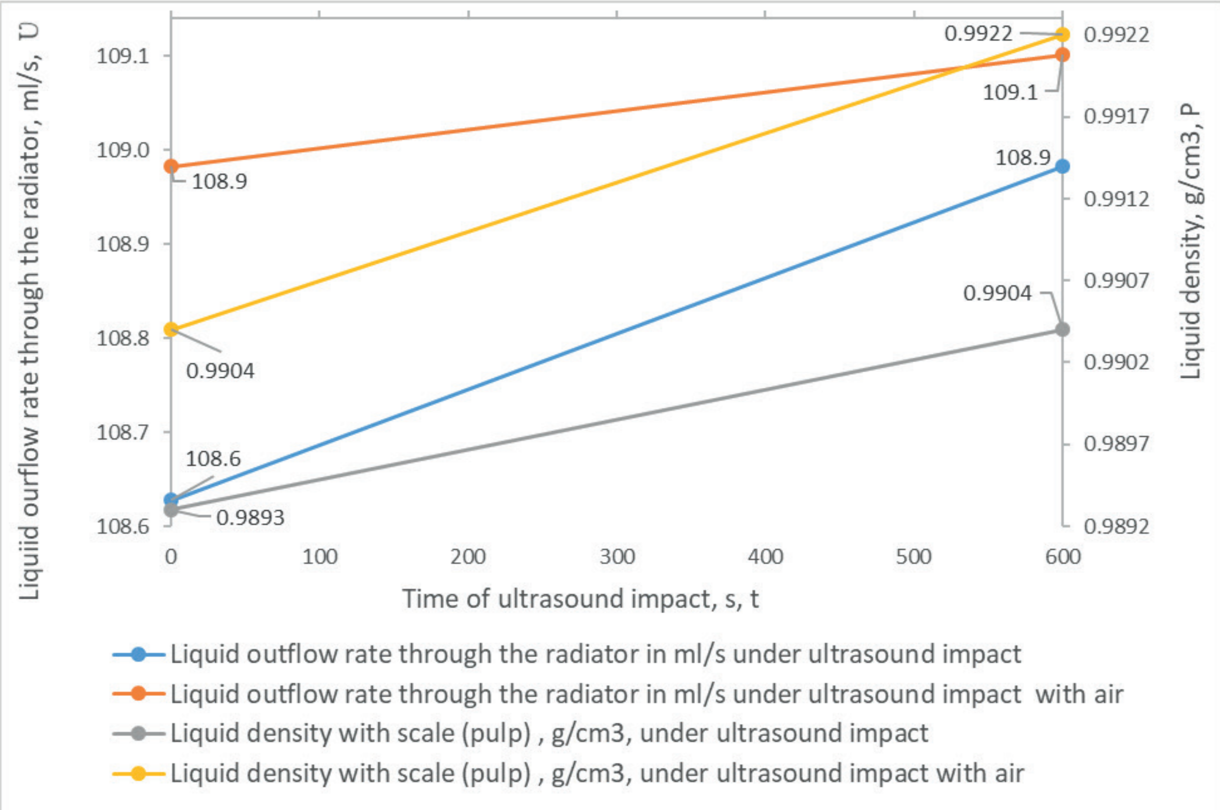


***Figure 14** Changing the density and the liquid outflow rate through the car radiator when the water is saturated with air*

process is 40…60 Celsius degrees [26]. When the specified temperature is exceeded, the rate of grinding scale particles decreases, therefore, the process of cleaning the car radiator will decrease. For the experiment, the temperature range of 50-51 °C has been selected.

According to the ratios of the scale mass to the liquid outflow rate with different periods of impact, the coefficients of cleaning efficiency have been determined (Figure 13):

$$K_m = \frac{m_{1...3} \times 100\%}{m_0}, \quad K\upsilon = \frac{\upsilon_{1...3} \times 100\%}{\upsilon_0}, \quad K_p = \frac{p_{1...3} \times 100\%}{p_0}, \qquad (1)$$

where: Km, K_υ and K_p are coefficients that characterize increasing the scale mass, the density and the liquid outflow rate from the radiator depending on the time of ultrasound impact;

$m_{1...3}$ is the scale mass depending on the time of ultrasound impact;

$U_{1...3}$ in the liquid ourflow rate depending on the time of ultrasound impact;

$P_{1...3}$ is the pulp density depending on the time of ultrasound impact.

The obtained coefficients in Figure 13 characterize the efficiency of cleaning the radiator. The physical meaning of the coefficients Km, K_υ and Kp consist in reflecting the processes occurring under the impact of liquid cavitation under the action of ultrasound and characterize the efficiency of scale destruction in the radiator tubes.

At the second stage of the experiment, water has been saturated with air using a compressor. Then the experiment has been repeated according to the first plan, and according to the obtained measurable parameters (Table 4), a graph has been built (Figure 14).

The dependences obtained in Figure 14 indicate increasing the liquid cavitation when saturated with air. When exposed to an ultrasonic wave and saturating the flushing liquid with air using a compressor, it improves the process of cleaning the radiator tubes.

4 Conclusion

The literature analysis of ultrasonic cleaning systems carried out led to the conclusion that such ultrasonic effects were not used to clean the radiators of the motor vehicle cooling system.

The hypothesis about the possibility of developing a method of cleaning radiator tubes from scale using ultrasonic exposure has been experimentally proven, while the results of the experiment have shown the following:

- the rate of fluid outflow from the radiator tubes after ultrasonic exposure increases. This is caused by increasing the internal section of the tubes as a result of descaling;
- the density of the pulp is higher than the density of water and, according to the curvilinear dependence, it increases with the time of exposure to ultrasound;
- the mass of scale released also depends on the cleaning time;
- when the water temperature rises, the cleaning process accelerates, as the intensity of cavitation increases;
- the more water is saturated with air, the more intensive the cleaning process. The impact is almost linear.

The results obtained make it possible to prove scientific and practical significance for the development of a methodology of calculating the parameters of the technological process of maintaining the radiators.

References

[1] VAKHLAMOV, V. K. *Cars: the basics of design: a textbook for students of institutions of secondary vocational education*. Moscow: Academy, 2007. ISBN 978-5-7695-4230-5.

[2] PUCHIN, E. A., GADZHIEV, A. A., KONONENKO, A. Repair of radiators of the cooling system of internal combustion engines. Textbook. Moscow: FGOU VPO MGAU, 2006.

[3] KADYROVA, I. A., MINDUBAYEVA, F. A., GRJIBOVSKI, A. M. Prediction of outcomes after stroke: a systematic review. *Human Ecology*. 2015, **2015**(10), p. 55-64. ISSN 1728-0869.

[4] KADYROV, A., GANYUKOV, A., PAK, I., SULEYEV, B., BALABEKOVA, K. Theoretical and experimental study of operation of the tank equipment for ultrasonic purification of the internal combustion engine exhaust gases. *Communications - Scientific Letters of the University of Zilina* [online]. 2021, **23**(3), p. B219-B226. ISSN 1335-4205, eISSN 2585-7878. Available from: https://doi.org/10.26552/com.C.2021.3.B219-B226

[5] KADYROV, A., ZHUNUSBEKOVA, Z., GANYUKOV, A., KADYROVA, I., KUKESHEVA, A. General characteristics for loading the working elements of drilling and milling machines when moving in the clay solution. *Communications - Scientific Letters of the University of Zilina* [online]. 2021, **23**(2), p. B97-B105. ISSN 1335-4205, eISSN 2585-7878. Available from: https://doi.org/10.26552/com.C.2021.2.B97-B105

[6] KADYROV, A., SARSEMBEKOV, B., GANYUKOV, A., ZHUNUSBEKOVA, Z., ALIKARIMOV, K. Experimental research of the coagulation process of exhaust gases under the influence of ultrasound. *Communications - Scientific Letters of the University of Zilina* [online]. 2021, **23**(4), p. B288-B298. ISSN 1335-4205, eISSN 2585-7878. Available from: https://doi.org/10.26552/com.C.2021.4.B288-B298

[7] KADYROV, A. S., KUNAYEV, V. A., GEORGIADI, I. V. Ferrous metallurgy waste and waste technical fluids for obtaining the material of road bases. *Ecology and Industry of Russia* [online]. 2017, **21**(12), p. 44-48. ISSN 1816-0395. Available from: https://doi.org/10.18412/1816-0395-2017-12-44-48

[8] [8]KADYROV, A., KARSAKOVA, A., DONENBAYEV, B., BALABEKOVA, K. Establishing the strength characteristics of the lifting-leveling device structures of the VPO-3-3000 machines for the track straightening. *Communications - Scientific Letters of the University of Zilina* [online]. 2020, **22**(4), p. 70-79. ISSN 1335-4205, eISSN 2585-7878. Available from: [9] https://doi.org/10.26552/com.C.2020.4.70-79

[10] IBATOV, M. K., KADYROV, A. S., PAK, I. A., KADYROVA, I. A., ASKAROV, B. S. The results of experimental studies of the capacitive equipment of ultrasonic cleaning of exhaust gases of vehicles. *Ugol / Coal* [online]. 2020, **2**, p. 73-78. ISSN 0041-5790. Available from: https://doi.org/10.18796/0041-5790-2020-2-73-78

[11] KADYROV, A., GANYUKOV, A., IMANOV, M., BALABEKOVA, K. Calculation of constructive elements of mobile overpass. *Current Science* [online]. 2019, **116**(9), p. 1544-1550. ISSN 0011-3891. Available from: https://doi.org/10.18520/cs/v116/i9/1544-1550

[12] KADYROV, A., KUNAEV, V., GEORGIADI, I., KHAIBULLIN, R. Advanced methods for solving the problems of road construction in central Kazakhstan. *Tehnicki Vjesnik* [online]. 2019, **26**(4), p. 1159-1163. ISSN 1330-3651. Available from: https://doi.org/10.17559/TV-20170225144013

[13] KADYROV, A. S., AMANGELDIYEV, N. E. New specifications of the theory of ground cutting. *Periodico Tche Quimica*. 2019, **16**(31), p. 922-936. ISSN 1806-0374.

[14] KADYROV, A. S., KUNAYEV, V. A., GEORGIADI, I. V. Prospects for processing of ferrous metallurgical waste based on arcelormittal temirtau experience. *Metallurgist* [online]. 2018, **62**(1-2), p. 22-28. ISSN 0026-0894. Available from: https://doi.org/10.1007/s11015-018-0620-3

[15] GANYUKOV, A., KADYROV, A., BALABEKOVA, K., KURMASHEVA, B. Tests and calculations of structural elements of temporary bridges / Badania i obliczenia elementów konstrukcyjnych mostów tymczasowych (in Polish). *Roads and Bridges / Drogi i Mosty* [online]. 2018, **17**(3), p. 215-226. ISSN1643-1618. Available from: https://doi.org/10.7409/rabdim.018.014

[16] KADYROV, A., BALABEKOVA, K., GANYUKOV, A., AKHMEDIYEV, S. The constructive solution and calculation of elements of the unified module of the mobile bridge overcrossing. Transport Problems [online]. 2017, **12**(3), p. 59-69. ISSN 1896-0596. Available from: https://doi.org/10.20858/tp.2017.12.3.6

[17] ZHUNUSBEKOVA, Z. Z., KADYROV, A. S. Study of digging machine flat element loading in clay solution. *Scientific Bulletin of National Hirnichoho University*. 2016, **2**, p. 30-33. ISSN 2071-2227.

[18] KADYROV, A., PAK, I., GANYUKOV, A., IMANOV, M., BALABEKOVA, K. Research of operation of equipment for ultrasonic purification of exhaust gases of internal combustion engines. *Journal of Engineering Physics and Thermophysics* [online]. 2021, **94**(6), p. 1407-1414. ISSN 1062-0125, eISSN 1573-871X. Available from: https://doi.org/10.1007/s10891-021-02447-x

[19] NASAD, T. G., SHEROV, K. T., ABSADYKOV, B. N., TUSUPOVA, S. O., SAGITOV, A. A. ABDUGALIYEVA, G. B., OKIMBAYEVA, A. E. Formation management in parts processing regenerated by surfacing. *News of the National Academy of Sciences of the Republic of Kazakhstan, Series of Geology and Technical Sciences*. 2019, **3**(435), p. 102-108. ISSN 2224-5278.

[20] Patent of the Republic of Kazakhstan No. 3194. Device for ultrasonic purification of exhaust. 2018.

[21] BALDEV, R., RAJENDRAN, V., PALANICHI, P. *Applications of ultrasound*. Moscow: Technosphere, 2006. ISBN 5-94836-088-1.

[22] BERGMAN, L. *Ultrasound and its application in science and technology*. BERGMAN, L., GRIGORIEVA, V. S., ROSENBERG, L. D. Moscow: Publishing House of Foreign Literature, 1957.

[23] KHODZHIBERGENOV, D. T., ESIRKEPOV, A., SHEROV, K. T. Rational milling of metals. *Russian Engineering Research*. 2015, **35**(1), p. 43-45. ISSN 1068-798X.

[24] KADYROV, A., GANYUKOV, A., BALABEKOVA, K. Development of constructions of mobile road overpasses. *MATEC Web of Conferences* [online]. 2017, **108**, 16002. eISSN 2261-236X. Available from: https://doi.org/10.1051/matecconf/201710816002

[25] KADYROVA, I. A., KADYROV, A. S. Alterations of serum neurospecific proteins concentrations in patients with metabolic syndrome. *Journal of Neurology and Psychiatry named after S. S. Korsakov* [online]. 2016, **116**(11), p. 92-97. ISSN 1997-7298. Available from: https://doi.org/10.17116/jnevro201611611192-97

[26] KADYROV, A. S., PAK, I. A., KADYROVA, I. A., GANYUKOV, A. A. Physics of the process of ultrasonic coagulation of exhaust gases of internal combustion engines of motor vehicles. *Bulletin of PSU. Energy Series*. 2020, **1**, p. 219-230. ISSN 1811-1858.

[27] IBATOV, M. K., KADYROV, A. S., PAK, I. A., KADYROVA, I. A., ASKAROV, B. S. Results of experimental studies of the operation of capacitive equipment for ultrasonic cleaning of vehicle exhaust gases. *Ugol / Coal* [online]. 2020, 2, p. 73-78. ISSN 0041-5790. Available from: https://doi.org/10.18796/0041-5790-2020-2-73-78